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Using fire to promote biodiversity

Submitted version

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One Sentence Summary: Biodiversity can benefit from fires that are tailored to suit the needs of particular ecosystems and species.

Main Text:

All around the world fire is profoundly influencing people, climate, and ecosystems (1). And the impacts of this interaction are likely to grow with climate models forecasting widespread increases in fire frequency and intensity because of increasing global temperatures (2). The survival of many plant and animal species depends on understanding how fire affects biodiversity (3), but addressing this component of the “worldwide wildfire problem” is complex (4). On one hand, many plants and animals require fire for their survival. On the other, even within fire-prone ecosystems, some species and communities are highly sensitive to fire. How then, can a fire regime support the conservation of species with different requirements? And how can we achieve this in a rapidly changing world?

An appealing and influential concept in ecology is that more diverse environments tend to have higher biodiversity (5). In the context of fire and biodiversity, this concept has encouraged diversity in fire regimes under the hypothesis that “pyrodiversity promotes biodiversity” (6). This hypothesis posits that increasing spatial and temporal variation in fires produces a greater

variety of ecological niches and therefore supports the coexistence of more species (6). This idea is only now being tested at large scales.

In a recent paper, Tingley *et al.* (3) significantly advanced understanding of pyrodiversity by analyzing how variation in fire history shapes bird diversity in conifer forests of California, USA. They collected an outstanding data set of >38,000 observations of birds, sampled across >1000 sites and 97 fires that varied in time since the last fire and burn severity. Bird diversity increased with pyrodiversity – fires with greater variation in burn severity had more species – and this effect increased in the decade following fire. Different burn severities created unique habitats, including areas with low and high cover of trees, whose bird communities differed over time (3). Some species in this region, such as the black-backed woodpecker, are dependent on habitat created by severe burns (7). Tingley *et al.* provide strong evidence that conifer forests with high variation in fire severity, a type of forest fire reduced by a legacy of fire suppression, are critical for sustaining biodiversity.

Another recent study also demonstrates that more species occur in areas with a high diversity of fire histories. Ponisio *et al.* (5) collected >7000 pollinator specimens, from 71 flowering plants species, in sites representing variation in fire interval and burn severity in conifer forests of Yosemite National Park, California. The number of unique pollinator visits to flowering plants was positively associated with increasing pyrodiversity, in correspondence with higher diversity of both pollinators and plants in areas with higher variation in fire interval and severity. This study is further evidence that variation in fire regimes supports the coexistence of more species in conifer forests and, importantly, it indicates that pyrodiversity can promote biodiversity through interactions across trophic levels (5).

However, it is more complex than simply saying that more variety equals better biodiversity outcomes. Determining the amount and type of pyrodiversity appropriate to different ecosystems remains essential because some studies show that increasing variation in fire regimes does not necessarily increase biodiversity. In semi-arid eucalypt woodlands of Australia, for example, the diversity of birds was not correlated with increasing spatial variation in pyrodiversity (8). In eucalypt woodlands, Berry *et al.* (9) found that large patches of long-unburnt vegetation have particularly high levels of bird diversity because they contain critical food and shelter resources, such as large trees, that support many species. Together, recent studies by Tingely *et al.*, Ponisio *et al.* and Berry *et al.* show that it is important to consider how fire influences both the diversity and area of suitable habitat across a suite of species (3, 5, 9).

While increasing pyrodiversity does not necessarily increase biodiversity in all ecosystems, research on fire-driven variation is proving valuable in developing new, theory-based approaches for determining fire patterns that support biodiversity (10). For example, plant life-history traits including the time to reproductive maturity and senescence can help estimate lower and upper limits of intervals between fires that best support species with different requirements (11). Identifying appropriate limits for other characteristics of fires, such as severity and patch size, is in its infancy. This is another reason why new research by Tingely *et al.* and others is important. By quantifying relationships between pyrodiversity and biodiversity we can begin to define “bounded ranges of variation” for multiple characteristics of fires (12), tailored to support particular ecosystems and species (figure).

But fire and biodiversity cannot be understood in isolation from other drivers of environmental change. Enright *et al.* (2) recently showed that a hotter, drier climate will reduce the range of fire intervals that allows plants to persist. This “interval squeeze” is caused by changing levels of

moisture under climate change that influence plant growth and reproduction; and has the potential to alter ecosystem structure (2). Plant species particularly vulnerable to interval squeeze are those dependent on canopy stored seeds for population recovery after fire. This includes species from iconic families of shrubs, such as Hooker's banksia (Proteaceae), found in biodiversity hotspots in Australia and South Africa (2). Clearly, linking plant and animal relationships with pyrodiversity also requires an understanding of feedbacks between fire regimes, biodiversity and ecosystems (10).

Fire-prone ecosystems are changing in other ways. Urbanization in southern Australia and western USA, regrowth of forests on abandoned land in Europe's northern Mediterranean, deforestation in tropical South America and Asia, and invasive plants in South Africa are all radically modifying fire regimes and biodiversity (1, 4, 11, 13). Developments in fire ecology reported here provide researchers with new avenues to couple models of animal and plant responses to fire with landscape simulations and scenarios analyses to make predictions of biodiversity change in these complex landscapes. Rapid progress in the development of models and decision tools, including through global efforts such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), is also helping to make better choices about when and where to conduct planned burning and fire suppression, while considering uncertainties such as the occurrence of wildfires and droughts (8).

These new tools and approaches are progressively being put to work by land managers and policy makers (1, 4, 8). One practical challenge is to integrate the growing scientific knowledge of pyrodiversity-biodiversity relationships with valuable place-based knowledge of fire held by people. Pyrodiversity has been connected to traditional burning by indigenous people in Australia and North America, and farmers in Europe and tropical savanna (6, 10, 13). For

example, research in the deserts of Western Australia is providing insights into how Aboriginal hunting fires support the coexistence of multiple species by generating variation in the size of unburnt patches (13). Moreover, partnerships between scientists and indigenous land owners in savanna landscapes of Arnhem Land, northern Australia, is showing how use of fire that incorporates traditional practices (e.g. implementing cool, patchy burns) and contemporary practices (e.g. aerial planned burning) can achieve multiple objectives including biodiversity conservation and reduction in greenhouse-gas emissions (14).

Another practical challenge is management when there is uncertainty about biodiversity responses to fire. Adaptive fire management of highly flammable savannas of Kruger National Park, South Africa, points to a way forward in applying research (15). Here, fire management in landscapes supporting grazing animals such as elephants, sable antelope and zebra has been designed to achieve ecological objectives defined by bounded ranges of variation (or thresholds) in the area and intensity of fires. This adaptive approach is underpinned by experimental manipulation of alternative fire regimes and a framework involving ongoing research, monitoring and evaluation. One measure of success is that fire management policy in Kruger NP changed as understanding of fire expanded (15).

A surge of new work has advanced knowledge of how spatial and temporal variation of fire influences biodiversity but there is a need to further develop approaches that are better tailored to local conditions. The identification of critical limits or thresholds in patterns of fires that support particular taxa and ecosystems, and how these vary among different and changing landscapes, remain outstanding questions requiring further research. Large-scale data on fire and biodiversity are becoming increasingly available, creating tremendous opportunities for cross-continental comparisons. There is now an exciting opportunity to narrow the gap between current fire

management and fast-growing knowledge of plant and animal interactions with fire. New and interdisciplinary approaches involving ecologists, climate and fire modellers, scenario planners and social scientists will help to ensure we better understand and use fire to promote biodiversity.

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Fig. 1.

Connecting pyrodiversity to biodiversity

Biodiversity can benefit from variation in fire regimes tailored to suit the needs of particular ecosystems and species.

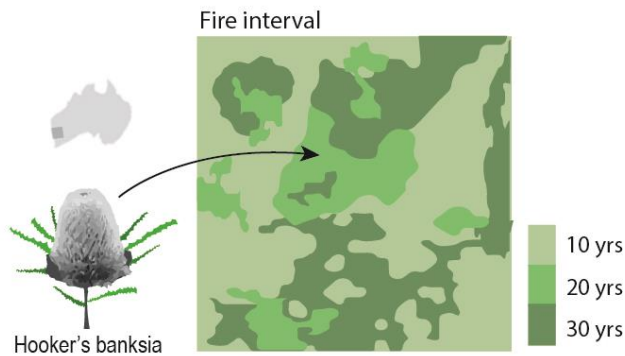
Spatial variation of fire

Knowing how animals are influenced by the diversity, size and arrangement of fire attributes, such as fire severity, can guide conservation management. The role of biotic interactions, including plant-pollinator relationships, is also an important consideration.



Temporal variation of fire

Life-history traits of plants, including time to reproductive maturity and senescence, can be used to estimate lower and upper bounds of fire intervals that support biodiversity. In some ecosystems, a drier climate is reducing the range of fire intervals that allow plants to persist.



Photo

Planned burning in Albacete, east-central Spain (C. Vilarasau, Pau Costa Foundation)

